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Color Stability of Different CAD/CAM Complete Denture Resins

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Color stability of different CAD/CAM complete denture resins

ABSTRACT

Purpose. The purpose of this *in vitro* study was to evaluate the color stability of resins for complete dentures produced with different technologies after immersion in coffee solution.

Materials and Methods. 50 square-shaped specimens were prepared from different resins for complete dentures (n=10): Probase Hot (PH; Ivoclar AG), IvoBase CAD (IBC; Ivoclar AG), Ivotion Dent white (ID, Shade A2; Ivoclar AG), Dima Print Denture Base (DPDB; Kulzer), Dima Print Denture Teeth (DPDT, Shade A2; Kulzer). One side of each specimen was polished according to manufacturers' instructions (POL) while the other one was left unpolished (UNPOL) (T_0). The specimens were immersed in a coffee solution at 37 °C for 28 days (T_{28}). During the storage period, the staining solution was replaced every 24 h. The CIELab color differences (ΔE_{ab}) between the different time intervals were evaluated using a live-video comparative spot digital colorimeter (Smart_Vision). Data were collected and statistically analyzed ($p < 0.05$).

Results. The highest color stability was recorded for IBC UNPOL ($\Delta E = 0.32$; $p < 0.05$). All specimens scored an acceptable ΔE , except for DPDT UNPOL ($\Delta E = 4.56$) which scored significantly lower as compared to all the other specimens ($p > 0.05$).

Conclusions. Milled and 3D printed resins for complete dentures demonstrated comparable color stability to traditionally-fabricated materials. Polishing influenced the color stability only in the 3D printed white resin where the unpolished group reached an clinically unacceptable level of color change after staining.

INTRODUCTION

Complete removable dental prostheses (CRDPs) represent a well-established therapeutic solution for the rehabilitation of edentulous patients. Traditionally, these prostheses have been fabricated using the compression molding or heat-polymerized techniques of polymethyl

methacrylate (PMMA). While effective, these conventional methods involve labor-intensive procedures, are time-consuming, and require significant material consumption.¹

The advent of digital technologies in dentistry has revolutionized the fabrication of dental prostheses, offering more efficient workflows and the potential for improved material performances.² In the realm of complete removable prostheses, digitally fabricated resins have gained considerable traction.³⁻⁴ Clinicians and patients alike have expressed high levels of satisfaction with digitally processed prostheses compared to those produced using conventional methods.⁵⁻⁷

Digital techniques have rationalized both clinical protocols and manufacturing processes for CRDPs.⁸⁻⁹ These techniques can be broadly categorized based on the fabrication process: subtractive methods, such as computer-aided design and manufacturing (CAD/CAM), and additive methods, such as 3D printing. CAD/CAM involves milling prostheses from pre-fabricated PMMA blocks, which are produced under high pressure and temperature to minimize shrinkage in the final restoration.¹⁰ These blocks are available in various forms, including pink resin for denture bases, white resin for teeth, or mixed blocks that allow for the complete fabrication of a prosthesis in a single milling process.¹¹⁻¹²

On the other hand, 3D printing technology is gaining recognition as a promising alternative for CRDP fabrication, although its current use in clinical practice is primarily for provisional restorations.¹³ Research comparing the physical properties of 3D-printed and milled prostheses remains limited, especially in terms of long-term performance.¹⁴

For dental materials used in CRDPs, including resins, it is crucial to meet specific mechanical, physical, and biological criteria to ensure durability in the challenging conditions of the oral cavity. One key aspect is chromatic stability, particularly given the complexity of the oral environment in edentulous, often elderly, patients. Maintaining color stability over time is essential for both aesthetic and functional reasons.¹⁵⁻¹⁶

Although there have been initial studies on the mechanical properties of these resins, there is limited research specifically focused on their color stability, especially with the increasing adoption of 3D printing technology. A deeper understanding of how these materials resist discoloration is needed to encourage their long-term use in clinical practice.

Therefore, the aim of this *in vitro* study was to evaluate the color stability of various resins used for the fabrication of CRDPs, comparing subtractive CAD/CAM methods and additive 3D printing techniques to the conventional heat-polymerized PMMA process. The hypothesis tested in this study was that there would be no significant differences in the color stability between the different resin types.

MATERIALS AND METHODS

1. Specimens preparation

Five types of PMMA resins for CRPDs with different fabrication techniques (Table 1) were tested (n=10): one heat-polymerized resin (PH; Probase Hot, Ivoclar AG, Schaan, Liechtenstein), two CAD/CAM resins (IBC: IvoBase CAD and ID; Ivotion Dent white color A2, Ivoclar AG) and two 3D-printed resins (DPDB: Dima Print Denture Base and DPDT: Dima Print Denture Teeth, Kulzer, Tokyo, Japan). Products' chemical and general information are provided in Table 1.

A total of 50 resin specimens of standardized dimension (10×10×3 mm) were obtained and tested. Sample size was calculated based on a pilot study using G*Power 3.1.9.7 for Windows. The calculation demonstrated that the necessary sample size was 10 specimens per group, with an effect size $f = 0.6434499$, $\alpha = 0.05$ and power $[1 - \beta \text{ error probability}] = 0.90$. A specimen of each group is shown in Fig. 1.

Specimens belonging to the PH group were produced as follows: initially wax patterns were made to the required specimen size (10×10×3 mm) and then two flasks were filled using type II gypsum (Gibraltar-Plaster, Henry Schein Krugg, Bologna, Italy). After removing the wax

model with hot water, two layers of gypsum-resins insulator (Separating Fluid, Ivoclar AG) were applied. A mixture of heat polymerized acrylic resins was prepared according to the manufacturer's instructions at a proportion of 22.5 g of powder and 10 ml of liquid and at dough stage packed into the mold. The flask was closed and placed in the hydraulic press at 8 MPa pressure. The flask was then placed in cold water, heated up to 100°C and boiled for 45 min according to the manufacturer's instructions.

Specimens produced with a milling technique were obtained from pre-polymerized PMMA discs starting from a standard tessellation language (.STL) file. The discs were sliced using a milling machine (Programill PM7, Ivoclar AG) and after milling was completed, the specimens were cut off from the PMMA bank using an acrylic trimming disc bur.

Specimens produced with an additive technique were fabricated with a 3D printer (Cara Print 4.0 Pro, Kulzer) starting from a standard tessellation language (STL) file. 3D printing was done with an incremental layer thickness of 100µm in a horizontal orientation. After the printing process was completed, the specimens were thoroughly cleaned by rinsing in 96% ethanol once for 3 min. After drying the specimens, they were post-cured in an ultraviolet light device (UV Everes Curo, Sweden & Martina, Padua, Italy) for 10 min to complete the curing process.

After fabrication, one side of each specimen was polished (POL). As to do so, a white goat brush mounted on a handpiece with 80 µm wet pumice (Pomice, Simed S.a.s., Turin, Italy) without water was used and eventually a deerskin brush with a polishing paste (Universal Polishing Paste, Ivoclar AG). After polishing procedures, each specimen was observed under magnification with loupes (3.5x) to check the surface quality ensuring the absence of flaws, voids or superficial irregularities. Afterwards, the dimensions were verified with a digital caliper.

The opposite surface of each specimen was left unpolished (UNPOL).

A coffee solution was used for staining purposes. The coffee medium was prepared using 4 g of soluble coffee (Nescafé Classic, Nestlé, Vevey, Switzerland) diluted in 120 mL of boiled water. The solution was left to cool at room temperature and then the resin specimens were immersed into the coffee medium and stored in a laboratory oven at 37 °C for 28 days. The coffee solution was replaced every 24 h. After the testing period, the specimens were removed from the staining solution, rinsed with distilled water, and dried with absorbent paper in order to test the color stability.

2. Color measurements

Color analyses were performed at baseline (T_0) and after storage in coffee solution (T_{28}). The color coordinates (L^* : lightness, a^* : red/green, and b^* : yellow/blue) were obtained with a latest generation live-video comparative spot digital colorimeter (Easy_Color, SmartVision, Udine, Italy). The Commission Internationale de l'Eclairage (CIE Lab) settings were as follows: observer degree: 2; ΔE type: ΔE_{ab} CIELAB ; Illuminant: D; Temperature: 50. White and black calibration was performed as suggested by the manufacturer at the beginning of the test and calibration was performed every 10 measurements. The first measurement allowed for recording a master model per each group. This model served as reference to detect any color variation with the subsequent measurements after staining.

The measurements were conducted by a single, trained operator. In summary, each specimen was placed on a viewing platform equipped with an LED light source and covered with a black cap. The position and dimensions of the analysis area (1.73×0.86 mm) were precisely adjusted and customized. This setup ensured that measurements could be repeated at the exact same location and with the same measurement size, either on the same specimen for multiple readings or on different specimens. This feature facilitated standardization and repeatability across various testing stages. The instrument enabled precise color analysis in a single session, lasting just 2 s. An initial color reading (T_0) was taken for each specimen using a master reference

model. The reference Lab^* values were then compared to the current readings, and the system automatically recorded the ΔE values. According to ISO/TR 28642 Dentistry-Guidance on Color Measurement (2016 Edition)¹⁷, color differences of $\Delta E < 1.2$ are imperceptible to the human eye while values of $\Delta E > 2.7$ are considered clinically unacceptable.

3. Statistical analysis

The normal (Shapiro–Wilk Test) and homogeneous (Levene test) distribution of the data was first assessed with R software, version 3.3.3 (R Foundation for Statistical Computing, Vienna, Austria). However, since data were not normally ($P=0$) and non homogeneously distributed ($P=0.8$), the Kruskal-Wallis non parametric test was conducted. Comparisons were made using the post-hoc Dunn’s test to determine statistically significant differences. The significance level was set at $P < 0.05$.

RESULTS

Data referring to color changes (ΔE_{ab}) for the different groups before and after immersion in coffee solution are reported in Tables 2 and 3 and Figures 2 and 3. IBC UNPOL demonstrated a significantly higher color stability ($\Delta E_{ab} = 0.32$) compared to PH UNPOL ($P=0.0031$), DPDB UNPOL ($P=0.0489$) and DPDT UNPOL ($P=0.0369$). Instead, DPDT UNPOL showed the worst color stability ($\Delta E_{ab} = 4.56$).

Except DPDT UNPOL, IBC POL ($\Delta E_{ab}=1.64$), ID POL ($\Delta E_{ab}= 1.92$) and ID UNPOL ($\Delta E_{ab}= 1.84$), all groups showed an imperceptible color change ($\Delta E_{ab} < 1.2$) irrespective of whether the surface was polished or not (PH POL: $\Delta E_{ab}=0.43$; PH UNPOL: $\Delta E_{ab}=1.2$; IBC UNPOL: $\Delta E_{ab}=0.32$; DPDB POL: $\Delta E_{ab}=0.89$; DPDB UNPOL: $\Delta E_{ab}= 0.53$).

No differences in color stability were found between the polished and unpolished specimens of each group except for the PH material ($P=0.0043$).

DISCUSSION

According to the results of this laboratory study, the resins produced with the conventional heat-polymerization, CAD/CAM and 3D printing methods obtained comparable color stability after polishing. The research hypothesis was partially supported, since IBC UNPOL demonstrated the lowest ΔE_{ab} value, indicating it to be the most stable among the materials tested. However, this distinction was observed only with the UNPOL (unpolished) surfaces. Conversely, after the polishing process, no statistically significant differences were observed among the resins (PH UNPOL, DPDB UNPOL and DPDT UNPOL).

Resin specimens obtained with digital techniques appear to have a similar color stability compared to those manufactured with conventional technology, and this was in agreement with Alp et al¹⁸, which evaluated the effect of coffee solutions on the discoloration of CAD-CAM acrylic resins and found that the color change in heat-polymerized and pre-polymerized CAD-CAM PMMA specimens were not significantly different.

The results obtained for 3D printed specimens are contrasting: DPDT shown a significant difference of color after immersion and recorded the worst color stability, in particular of the unpolished surface, while DPDB recorded a superior color stability compared to IBC. This lower color stability of white 3D-printed resin could be attributed to multiple reasons: milled PMMA resins have a high polymerization rate and high crosslinking, thus making them denser in comparison to 3D-printed PMMA resins. Different studies¹⁹⁻²¹ reported that milled and conventionally processed PMMA resins have MMA (methylmethacrylate)-based monomers that are hydrophobic, whereas HDMA (hexamethylene glycol dimethacrylate), which is the monomer used in light polymerized resins, is hydrophilic in nature. Thus, the higher polarity of 3D-printed PMMA resins could also be a reason for the lower color stability.

Another aspect that could influence the color stability is a lower filler content of the resin. Typically, 3D-printing resins contain a lower volume of inorganic filler particles than other

types of resins, as this helps to maintain low resin viscosity during the printing process and achieve a smooth surface finish.²² However, this lower filler content can also make the resin more susceptible to surface deterioration over time.²³ Additionally, the settling down of filler particles when the resin is printed can lead to nonhomogeneous layers, a further deterioration and a consequent decrease of color stability.²⁴

It is also possible that DPDT had higher residual monomer content, which could have contributed to their surface deterioration and absorption of color pigments with water, while DPDB had a lower residual monomer content. However, there is no current evidence demonstrating that the monomer content in 3D-printed resins are higher than other conventional and subtractively manufactured resins or that the monomer content could depend on the color of 3D-printed resins. Therefore, this assumption must be received with caution until future purpose-built studies prove this speculation.

Despite the results obtained, it should be considered that 100-micron layer thickness may influence the outcome; therefore, as indicated by Revilla-León et al.²⁵, it would be of interest for future studies to investigate whether reducing the layer thickness to 50 μm could yield different results.

All of these factors may have contributed to the decreased color stability observed in the white 3D-printed resin samples, therefore more research will be needed to investigate this aspect in the future.

The final ΔE_{ab} of all the resins tested was under the threshold of ISO/TR 28642, except for DPDT on the unpolished surface ($\Delta E_{ab} = 4.56$). Although these values appear to be unacceptable according to the ISO standard, other studies²⁶⁻³⁰ demonstrated that the magnitude of color difference (ΔE_{ab}) can have a range between 1.1 and 6.8. In particular, the results of this group may be considered acceptable according to Paravina et al.²⁷, which demonstrated that color differences are considered clearly unacceptable with a $\Delta E_{ab} > 5.4$.

In the present study, the worst data of DPDT was recorded on the unpolished surface. Both polished and unpolished surfaces were tested because during the polishing phase, the mucosa-side of the prosthesis (pink resin) is generally polished less. Therefore, the data obtained for white resins on the unpolished surface could be not clinically relevant since DPDT is a white resin that requires a polishing treatment.

Several staining solutions have been used in the literature to evaluate the color stability of various dental materials, including those employed in the fabrication of removable dentures³⁰. Among these, coffee is the most commonly used under experimental conditions, likely due to its widespread and habitual consumption in the general population.³¹ Moreover, coffee has been shown to exert a stronger effect on the discoloration of resin-based materials³², either by surface adsorption³³ or by altering the internal structure of the material.³⁴

In light of these considerations, coffee was selected as the staining medium for the present study. Even though a 7-day coffee immersion has been considered sufficient to produce color changes in resin-based materials³⁵, a 28-day immersion protocol has been more commonly adopted in literature, allowing for easier reproducibility and comparisons across studies.³⁶ Considering that 24 h of coffee immersion correspond to approximately 1 month of clinical service³⁷, a 28-day immersion can be assumed to simulate about 2 and a half years of clinical aging.

The current study has a few limitations. First, the experiment cannot replicate the exact oral environment. Conditions such as the composition of the saliva, pH fluctuations, oral hygiene, dietary habits, and masticatory function, amongst others, cannot be replicated in vitro studies. Second, thermocycling was not carried out. Even if the specimens were immersed in coffee solution and maintained at a constant 37 °C, to mimic the oral conditions, it must be noted that there are fluctuations in this temperature at meal times in clinical situations. The temperature fluctuations could be simulated during the thermocycling process. Therefore, in the future it

could be interesting to understand whether the same stain effects are also present on thermocycled or aged specimen.

It should be, moreover, considered that in this study the specimens were only evaluated after immersion in coffee solution. While it is hard to assume realistically the impact of the coffee alone without a counterpart group immersed in solely in saliva, it should be noted that previous research has shown that saliva generated the lowest color change among the groups after a 30-day immersion.³⁸

The absence of a saliva-only group in our study may limit our understanding of these effects, particularly considering that when water molecules are absorbed by acrylic resin, they act as plasticizers, compromising the material's mechanical resistance through the formation of microcracks associated with water uptake and hydrolytic degradation of the polymer matrix.³⁹

This process ultimately leads to chain scission and a gradual deterioration of the material's structural integrity.³⁹

Moreover, even though the digital colorimeter was able to retrieve faithful images from each model, a microscopic evaluation of the specimen surfaces before and after immersion was not carried out in this study. This could have clarified valuable informations on surface deterioration, if any, had been present, particularly referred to the white 3D printed resins which showed the highest color changes.

CONCLUSIONS

Within the limitation of this study, all resins tested demonstrated comparable color stability after immersion in coffee solution, irrespective of the fabrication method (heat-polymerizing method, CAD/CAM and 3D printing) and of the polishing procedure, except in case of the white 3D printed resin where polishing was deemed necessary as to obtain color stability.

248 Further studies are warranted to deeply evaluate the optical properties of the resins used to
249 produce complete removable partial dentures.

250 **Conflict of Interest:** The authors declare no conflict of interest.

251 **FIGURE LEGENDS**

252 **Figure 1.** Specimens. a: PH; Probase Hot (Ivoclar AG, Schaan, Liechtenstein). b: IBC, IvoBase
253 CAD, (Ivoclar AG, Schaan, Liechtenstein). c: ID; Ivotion Dent white color A2 (Ivoclar AG,
254 Schaan, Liechtenstein). d: DPDB, Dima Print Denture Base, Kulzer (Tokyo, Japan). e: DPDT,
255 Dima Print Denture Teeth, Kulzer (Tokyo, Japan).

256 **Figure 2.** Color change ($\Delta E = T_{28} - T_0$) of polished specimens after immersion in coffee. PH,
257 Probase Hot. IBC, IvoBase CAD. ID, Ivotion Dent. DPDB, Dima Print Denture Base. DPDT,
258 Dima Print Denture Teeth.

259 **Figure 3.** Color change ($\Delta E = T_{28} - T_0$) of unpolished specimens after immersion in coffee. PH,
260 Probase Hot. IBC, IvoBase CAD. ID, Ivotion Dent. DPDB, Dima Print Denture Base. DPDT,
261 Dima Print Denture Teeth.

262 **TABLES**

263 **Table 1.** Materials and technologies of production.

Materials	Composition	Technology
Probase Hot (PH) Ivoclar AG	Powder: Polymethyl methacrylate, softening agent, benzoyl peroxide, pigments Liquid: Methyl methacrylate, dimethacrylate (linking agent), catalyst	Heat-curing resin
IvoBase CAD (IBC) Ivoclar AG	Polymethyl methacrylate, co-polymer for impact toughness modification, pigments	Milling
Ivotion Dent (ID) Ivoclar AG	Highly corss-linked PMMA, pigments	Milling
Dima Print Denture Base (DPDB) Kulzer	Esterification products of 4,4'-isopropylidenediphenol, ethoxylated and 2-methylprop-2-enoic acid 7,7,9-trimethyl-4,13-dioxo-3,14-dioxo-5,12- diazahexadecane-1,16-diyl bismethacrylate Propylidynetrimethyl trimethacrylate Diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide Mequinol	3D Printing
Dima Print Denture Teeth (DPDT) Kulzer	Esterification products of 4,4'-isopropylidenediphenol, ethoxylated and 2-methylprop-2-enoic acid 7,7,9-trimethyl-4,13-dioxo-3,14-dioxo-5,12- diazahexadecane-1,16-diyl bismethacrylate Propylidynetrimethyl trimethacrylate Diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide Mequinol	3D Printing

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266 **Table 2.** Color changes (ΔE_{ab}). Final ΔE_{ab} indicates the median of color changes between T_{28}
267 and T_0 (Baseline).

Group		$T_0 \pm DS$	$T_{28} \pm DS$	FINAL ΔE_{ab} ($T_{28}-T_0$)	P VALUE
PH	POL	1.18 $\pm$ 1.0	1.61 $\pm$ 0.5	0.43	p>0.05
	UNPOL	5.08 $\pm$ 1.8	6.28 $\pm$ 0.8	1.2	p>0.05
IBC	POL	0.81 $\pm$ 0.1	2.45 $\pm$ 0.9	1.64	p>0.05
	UNPOL	1.22 $\pm$ 0.5	1.54 $\pm$ 0.4	0.32	p>0.05
ID	POL	3.59 $\pm$ 1.8	5.51 $\pm$ 1.3	1.92	p>0.05
	UNPOL	4.48 $\pm$ 1.2	6.32 $\pm$ 1.2	1.84	p>0.05
DPDB	POL	1.63 $\pm$ 0.2	2.52 $\pm$ 0.5	0.89	p>0.05
	UNPOL	4.97 $\pm$ 1.5	5.50 $\pm$ 0.8	0.53	p>0.05
DPDT	POL	0.75 $\pm$ 0.9	1.86 $\pm$ 0.8	1.11	p>0.05
	UNPOL	1.15 $\pm$ 0.4	5.8 $\pm$ 1.5	4.65	0.003087

268

269 **Table 3.** Differences in the color changes (ΔE_{ab}) between groups at T_{28} .

Group	VS Group	Mean difference in scores	Diff err std	Z	p value
PH POL	IBC UNPOL	111.500	25.88309	4.30783	0.0031
PH UNPOL	PH POL	109.650	25.88309	4.23636	0.0043
PH UNPOL	DPDT POL	103.450	25.88309	3.99682	0.0122
ID UNPOL	DPDT POL	100.750	25.88309	3.89250	0.0189
PH POL	DPDT UNPOL	-94.600	25.88309	-3.65490	0.0489
IBC UNPOL	DPDB UNPOL	-94.750	25.88309	-3.66069	0.0478
IBC UNPOL	DPDT UNPOL	-96.450	25.88309	-3.72637	0.0369
PH POL	ID UNPOL	-106.950	25.88309	-4.13204	0.0068

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